PLANET ANALOG all signal no noise

Signal Chain Basics

The basics of 4-20mA current loop transmitters

Collin Wells, Applications Engineer, Precision Analog, Texas Instruments, 5/5/2016

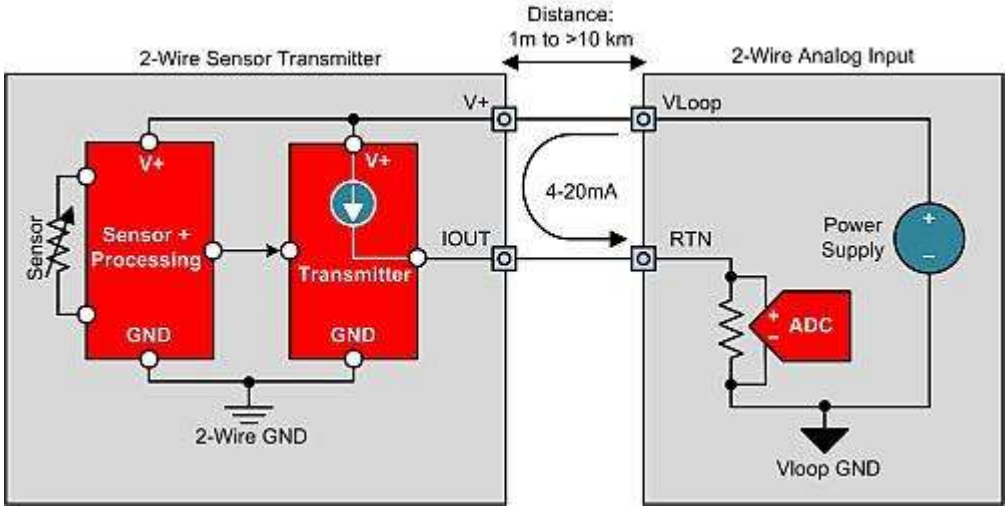
Editor's note: This month we are pleased to have Colin Wells from Texas Instruments as our blogger.

In modern industrial control systems, 4-20 mA current-loop transmitters remain one of the most common methods for transmitting data between control centers and sensors/actuators in the field. This is driven by their ease of use, installation and maintenance. The history of 4-20 mA current-loop transmitters began when pneumatic signals were used to control actuators and represent proportional controls in early industrial automation sites [1]. Typical pressure levels were 3 PSI – 15 PSI, where 3 PSI represented the zero-scale input/output and 15 PSI represented the full-scale input/output. If the pneumatic line ruptured, the pressure would fall to 0 PSI, representing a fault condition that needed to be addressed. Once electronics became common pneumatic lines were replaced with 4-20 mA current loops created from amplifiers, transistors and other discrete electronic components.

You may ask, "Why use a current loop?" Well, Kirchoff's laws state that current is constant in a closed loop. This allows you to run 4-20 mA current loops over extremely long distances with a constant current at any point in the loop, regardless of the wiring resistance. Of course, this requires sufficient loop voltage to maintain Ohm's Law. Similar to pneumatic systems, a broken or disconnected wire results in a loop current of 0 mA, or a "dead zero" fault condition that must be addressed. Additionally, current loops tend to be relatively easy to protect against damage from electrical transients and are inherently resilient against radio frequency interference (RFI) or electromagnetic interference (EMI) disturbances [2].

The most common type of 4-20 mA transmitter is the 2-wire topology, or a 2-wire sensor transmitter (**Figure 1**).

Figure 1



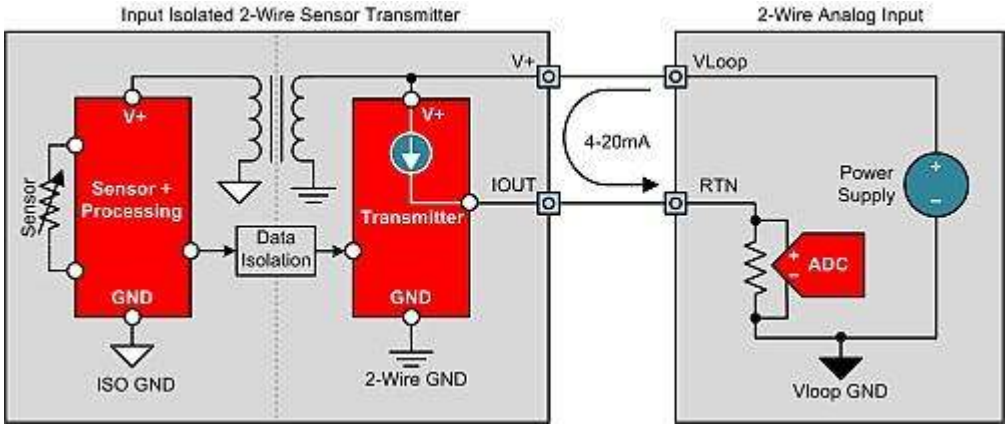
Simplified 2-wire 4-20 mA sensor transmitter with 2-wire analog input module

Two-wire sensor transmitters are used to transmit physical parameters from the field back to an analog input module for processing and control. Examples include pressure, position, temperature, level, strain, loading, flow, composition/ contamination. As the name suggests, this transmitter type features only two wires. Hence, the sensor receives power from the same two wires on which it communicates the 4-20 mA signal, defining one of the primary design requirements for two-wire 4-20 mA transmitters. The sensor, sensor-conditioning circuitry, and 4-20 mA transmitting circuitry must consume less than 4 mA of operating current, or the transmitter cannot output the 4 mA zero-scale level [3].

Note that the V_{LOOP} GND is not one of two connections provided to the 2-wire sensor transmitter. Therefore, the transmitter must create a local ground (GND), or 2-wire GND. This 2-wire GND must float up and down relative to the V_{LOOP} GND as the transmitter output current changes the voltage at the receiver return (RTN) connection [3]. Isolation is required if the sensor can be electrically connected to a voltage potential relative to the V_{LOOP} GND. This situation is common with thermocouple sensor transmitters because the thermocouple is often both thermally and electrically shorted to the material of which it is measuring temperature.

There is only one possible isolation topology for 2-wire transmitters: the input isolated 2-wire transmitter (**Figure 2**). Input isolated 2-wire transmitters generate a local isolated supply from the loop supply which powers the sensor, sensor conditioning circuitry, and isolated communication method. Digital isolation of pulse-width modulated (PWM), one-wire or serial peripheral interface (SPI) signals is the most common method to transmit data across the isolation barrier to the transmitter output stage.

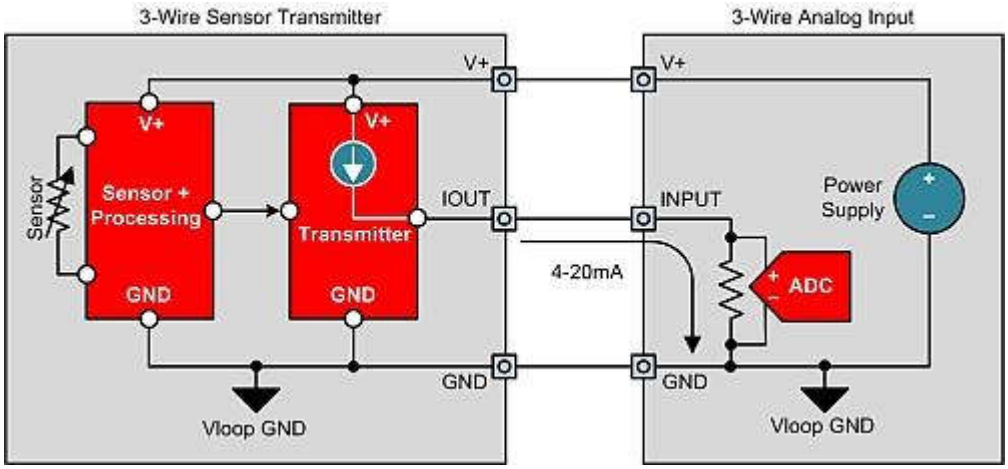
Figure 2



Simplified input isolated two-wire 4-20 ma sensor transmitter

As mentioned, 2-wire sensor transmitters are limited primarily because the entire sensor transmitter must consume <4 mA. This prevents many sensor types from being used, including low-resistance bridges (such as 100 Ω, 120 Ω, 350 Ω) without limiting the bridge current, which has the undesirable effect of reducing bridge sensitivity and accuracy. The 3-wire sensor transmitter topology (**Figure 3**) supports sensor transmitter designs that require >4 mA of operating current.

Figure 3

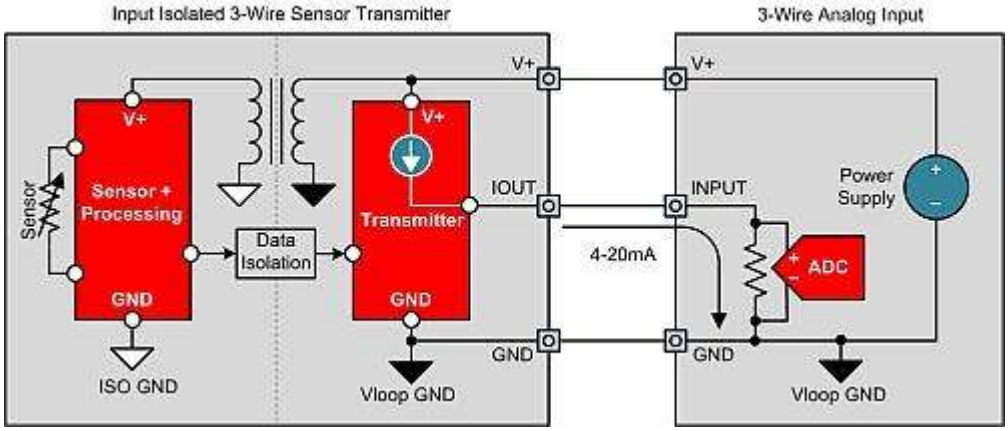


Simplified 3-wire sensor transmitter with 3-wire analog input module

Three-wire sensor transmitters receive power and GND connections from the 3-wire analog input module to support sensor and conditioning circuitry power requirements. This allows the sensor power to be as high as required without affecting the sensor output range (while maintaining Ohm's Law). This also enables 3-wire transmitters to create 0-20 mA and 0-24 mA outputs, which are other common output current ranges. Three-wire sensor transmitters are also used when voltage outputs (such as 0-10 V, ±10 V) are required.

There is also one isolation topology for 3-wire transmitters, if the sensor must remain isolated from the analog input module supply and GND potentials: the input isolated 3-wire transmitter. Input isolated 3-wire transmitters follow a similar isolation structure to input isolated 2-wire transmitters. A local isolated supply is generated for the sensor and sensor conditioning circuitry before the sensor information is passed over an isolation barrier to the 3-wire transmitter output stage.

Figure 4



Simplified input isolated 3-wire sensor transmitter

Conclusion

While 4-20 mA current-loop transmitters have been around for decades, they are still being actively used to communicate information in industrial factory automation and control applications. Field-level 2- and 3-wire sensor transmitters make up the majority of the market with three-wire programmable logic controller (PLC) analog outputs, and four-wire sensor transmitters capturing the rest of the market.

Please join us next time when we will discuss how precision current measurement optimizes motor control.

References

1. 4-20 mA transmitters Application Note, Dataforth Corporation
2. Duke, Kevin. Industrial DACs: How to protect 2-wire transmitters, Precision Hub, Texas Instruments, 2015
3. Wells, Collin. 2-Wire 4-20 mA Sensor Transmitters blog series, Precision Hub, Texas Instruments, 2015